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OVERVIEW OF DYNAMICS INTEGRATION RESEARCH (DIR) PROGRAM AT LANGLEY RESEARCH CENTER

Goals and Progress

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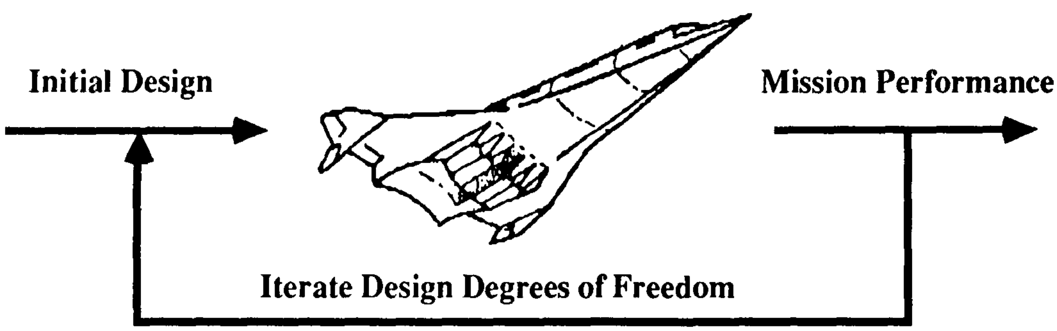
This presentation and paper describes research goals and objectives for an ongoing activity at Langley Research Center. The activity is aimed principally at dynamics optimization for aircraft. The effort involves active participation by the Flight Systems, Structures, and Electronics directorates at LaRC. The Functional Integration Technology (FIT) team has been pursuing related goals since 1985. A prime goal has been the integration and optimization of vehicle dynamics through collaboration at the basic principles or equation level. Some significant technical progress has been accomplished since then and this paper and some others at this symposium capture these results. An augmentation for this activity, Dynamics Integration Research (DIR), has been proposed to NASA Headquarters and is being considered for funding in FY 90 or FY 91.

C-2

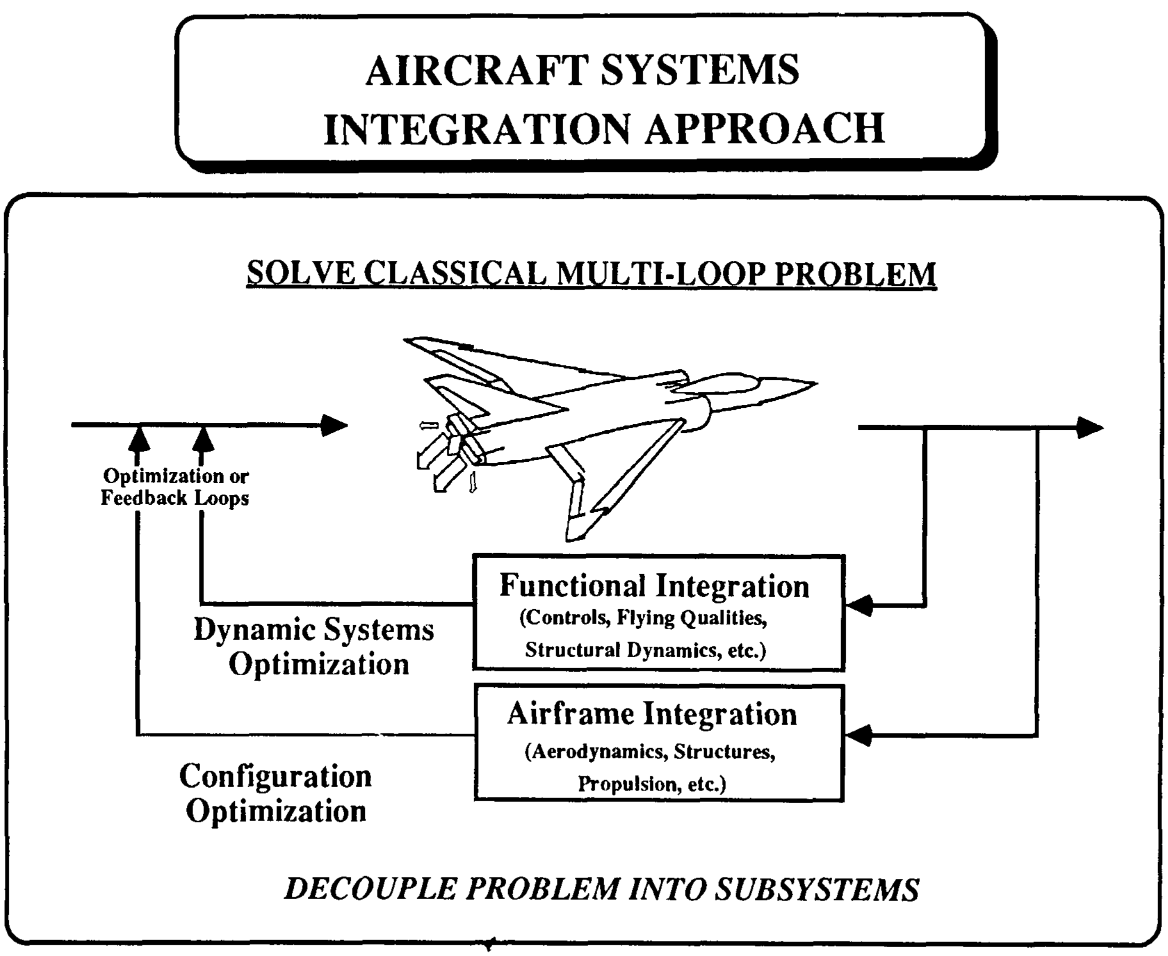
In 1984, NASA and several outside study groups (e.g., Aero 2000) identified multidisciplinary research as a key, untapped opportunity for aeronautical research. NASA Langley prepared a new initiative for pursuing this area. The overall goals and the kickoff chart are represented. If a capability existed to analytically model all the interactions and then numerical procedures were used to iterate the design variables until performance was optimized, many significant benefits would result. These include explicitly optimized configurations, all synergistic multidisciplinary interactions exploited, greater productivity in the design process and an opportunity to all designers to exercise more creativity. Truthfully, at the time, the plans did not go much deeper. An approach had not been worked out for accomplishing the research. The new initiative was not funded. Langley then put together a multidisciplinary technical team to make some recommendations on a technical approach.

AIRCRAFT SYSTEM INTEGRATION GOALS

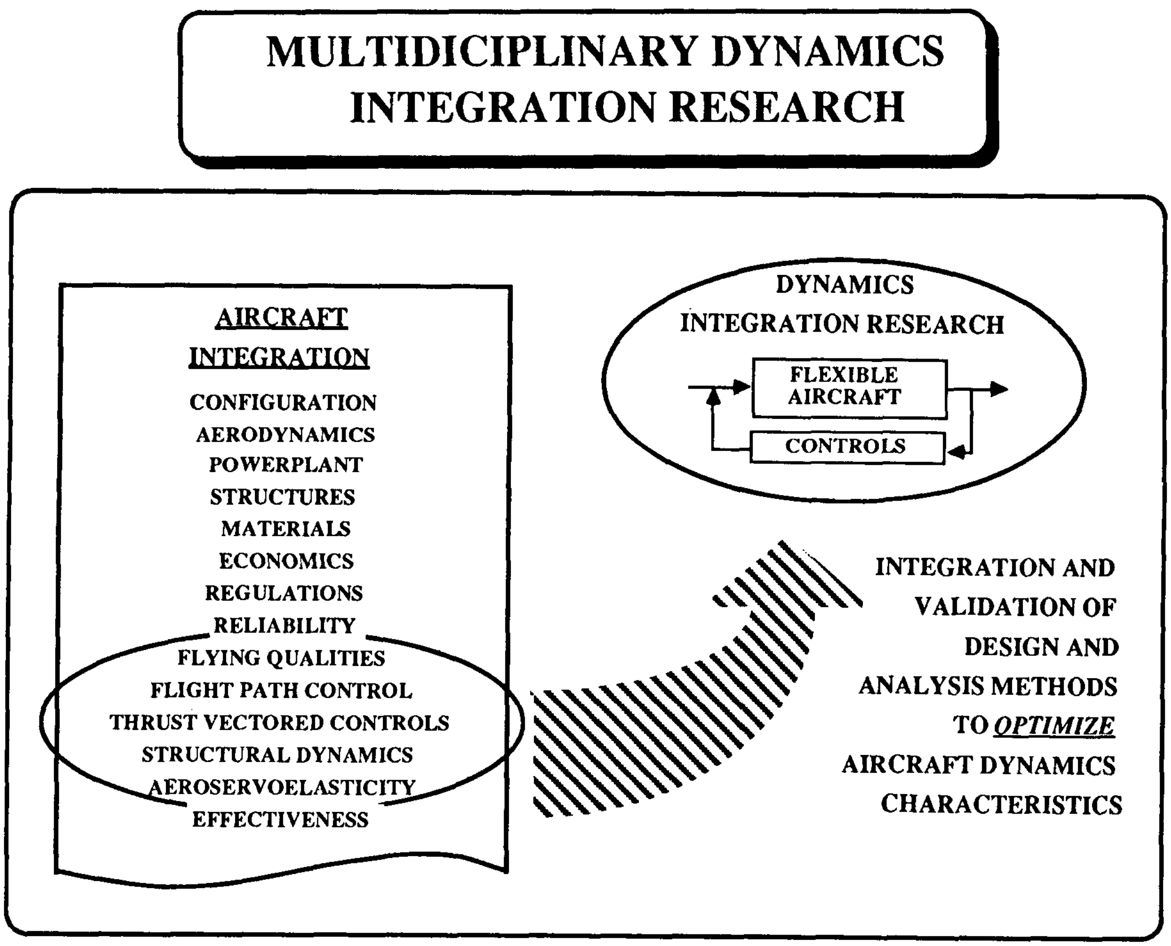


- o Explicitly Optimize Proposed Configurations
- o Synergistically Exploit Multidisciplinary Interactions
- o Speed Conceptual/Preliminary Design Process
- o Maximize Designer's Opportunity for Creativity

The technical planning team recommended that the problem be divided and solved in two parts simultaneously. This is a standard approach for solving complex problems and decomposing the problem into simpler elements for solution. In this case, the problem is separated into dynamics integration and airframe integration. Clearly these two problem areas are not completely decoupled, and, in fact, it is anticipated that the dynamics issues can significantly impact the overall design. However, a capability to perform the integrated dynamics optimization must exist before overall system optimization is possible. Two teams were formed at LaRC to attack these problems. One is the Aircraft Configuration Integration Group (ACIG) and the other is the Functional Integration Technology (FIT) team. The latter is the subject of this paper.

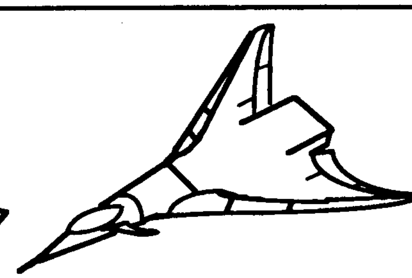


Overall aircraft system integration will require a long list of technologies and design variables to be combined and optimized. In the area of dynamics integration a subset of these issues has been selected for consideration in the research activity. Technologies being considered include flying qualities, flight path control, thrust vectored controls, structural dynamics, and aeroservoelasticity. The research goal is to develop and validate methods and tools which optimize aircraft dynamics, not just to analyze and solve problems.



Dynamics integration will be important in terms of enabling mission performance. The mission drivers below lead to the design options indicated. Taking advantage of the design options will result in aircraft characteristics that will have significant dynamics challenges to be resolved. Unstable aircraft will result from tailless configurations or reduced control surface sizes for performance and observability. Flexibility will result from minimum weight configurations which will involve coupling and unusual dynamics interactions between modes. Analysis tools will have trouble predicting these responses, many of which are strongly coupled with nonlinear phenomena. All of these challenges will have to be solved without adding to the already complex environment in which the pilot must operate the aircraft. The bottom line is that dynamics issues will play a first-order role in aircraft design.

PRESENT AND FUTURE TRENDS



MISSION DRIVERS

- o LOW OBSERVABLES
- o HIGH PERFORMANCE
- o EXPANDED ENVELOPES

DESIGN OPTIONS

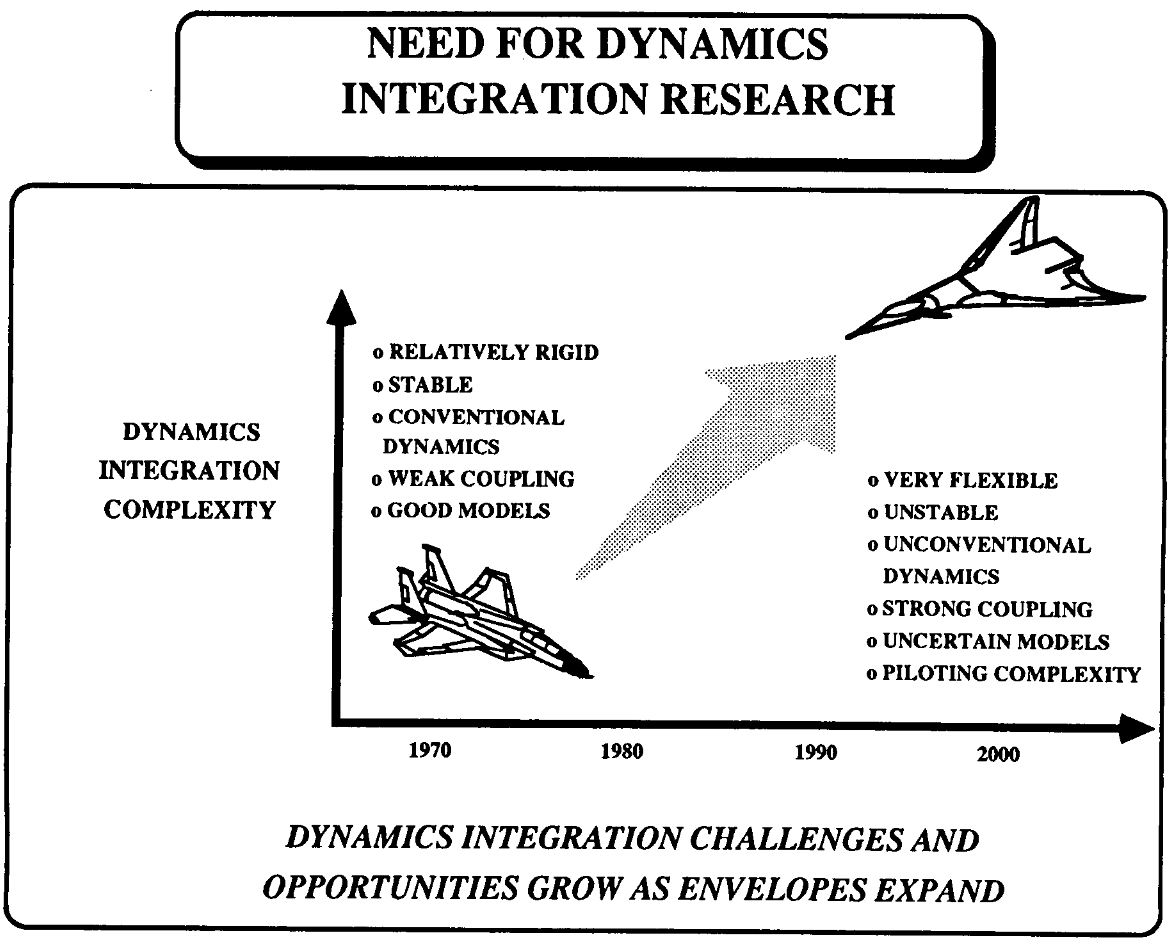
- o THRUST VECTORED CONTROLS
- o LIGHTWEIGHT COMPOSITES
- o NEW FLIGHT MODES
- o NO TAIL SURFACES

DYNAMICS CHALLENGES

- o UNSTABLE
- o VERY FLEXIBLE
- o UNCONVENTIONAL DYNAMICS
- o STRONG COUPLING
- o UNCERTAIN MODELS
- o PILOTING COMPLEXITY

DYNAMICS ISSUES PLAY A FIRST ORDER ROLE IN AIRCRAFT DESIGN!

The extreme technological demands placed upon the design for dynamics issues are new. The complexity has been increasing rapidly. Past configurations were relatively rigid, stable, and characterized by conventional dynamics. In fact, past configurations were deliberately designed with weak coupling between the modes. Existing tools are now capable of predicting most of the major influences for these conventional configurations. New and future configurations will demand that significant enhancements be made in the tools and methodologies to minimize risk and maximize performance.



There are examples of recent aircraft configurations that have had significant dynamics problems. Each of the cases listed below had controls and structural dynamics issues that cost tens of millions of dollars each to alleviate. The F series aircraft below encountered the indicated problems after first flight, which is very late in the design process, resulting in costly delays and expensive fixes. The fixes may not even be as complete as desired since options are significantly limited at that point. A goal of LaRC's DIR program is to make sure that technologies exist to help solve as many of these problems as possible before first flight; to find optimized, multidisciplinary solutions to as many of these problems as possible; and to link these solutions to the overall configuration.

RECENT EXAMPLES OF AIRCRAFT DYNAMICS PROBLEMS

F-16

CONTROLLER REDESIGN
DEPARTURE PROBLEMS
PROPULSION INTEGRATION
FLUTTER WITH STORES

X-29A

AEROSERVOELASTIC INTERACTIONS
EXTREME AUGMENTATION
SENSOR PLACEMENT
BACK-UP MODE COMPLICATIONS

F-18

LONG LAGS/DELAYS
SIMULATION FIDELITY
AILERON LIMIT CYCLE
CONTROL SATURATION

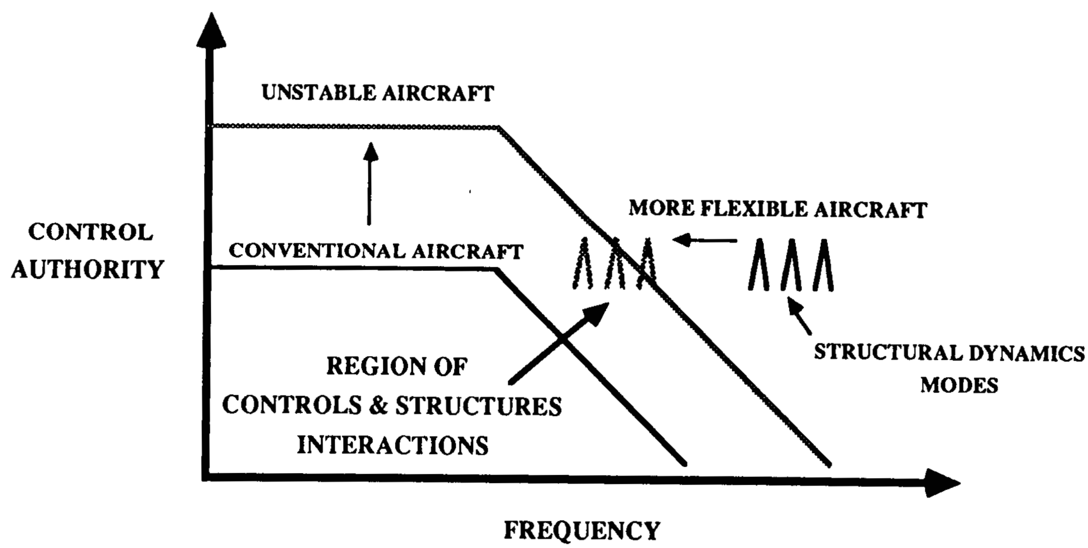
F-15

RUDDER OSCILLATION
POOR PITCH DAMPING
RUDDER LIMIT CYCLE
STABILATOR OSCILLATION

GOAL IS TO PROVIDE VALIDATED METHODOLOGIES TO SOLVE PROBLEMS PRIOR TO FLIGHT

The chart below illustrates the complications that are pervading new aircraft configurations as typified by the previous chart. This is a plot of control authority/power versus frequency of input. Sometimes this type of chart is referred to as a Bode chart. Typical structure is for some control authority at low frequencies to improve flying qualities and stability. However, an essential goal is to "roll off" the authority at high frequency to avoid interactions with actuator and structural modes. However, unstable aircraft require more augmentation at low frequency and cannot be "rolled off" as quickly. Additionally, as an aircraft becomes more flexible, the structural modes have lower frequencies. If the control authority and structural modes have significant intersections, the probability of complicated interactions is high.

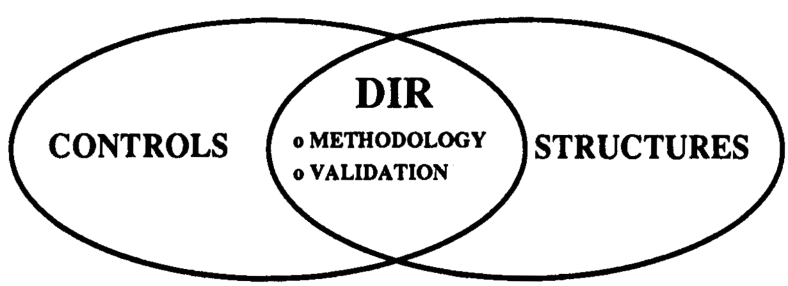
ILLUSTRATION OF GREATER DYNAMICS CHALLENGES



SIGNIFICANT DYNAMICS INTEGRATION CHALLENGES EXIST FOR UNSTABLE, FLEXIBLE AIRCRAFT

The research program defined by the Structures and Flight Systems directorates is depicted below. It entails methodology development and validation. Prime goals entail developing integrated modeling techniques and software tools and exploiting these to evolve design and synthesis methods. A major aspect of the proposed program is the validation of the design tools resulting from this program. Validation will occur in real-time piloted simulations and in wind tunnel tests of aeroservoelastic models in the Transonic Dynamics Tunnel. Funds are being sought to accelerate the program and to help facilitate technology transfer within the aerospace community.

TIMELY R&T BASE EFFORT TO FOCUS RESEARCH



METHODOLOGY DEVELOPMENT

- o MODELING TECHNIQUES AND SOFTWARE TOOLS
- o DESIGN AND SYNTHESIS METHODS

VALIDATION ACTIVITIES

- o AEROSERVOELASTICALLY TAILORED WIND TUNNEL MODEL TESTS
- o REAL-TIME PILOTED AND BATCH SIMULATIONS

TECHNOLOGY TRANSFER

- o INDUSTRY, DoD AND UNIVERSITY PARTICIPATION

This chart represents some of the payoffs that might be accomplished if such a program is fully funded. The list includes performance benefits if a configuration is completely redesigned to exploit technologies that might result from the DIR program. Additionally, increases in reliability and effectiveness of the design tools and methods result.

DIR PAYOFFS & GOALS

VEHICLE PAYOFFS & GOALS

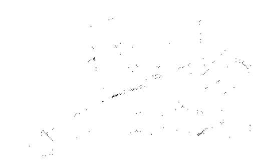
- o 25% INCREASE IN AIRCRAFT AGILITY
- o 15% INCREASE IN ENVELOPE VELOCITY WITH STORES
- o 30% DECREASE IN TAKE-OFF GROSS WEIGHT
- o SUPERSONIC PERFORMANCE UNCOMPROMISED DUE TO LOW-SPEED CONSTRAINTS AND FLYING QUALITIES
- o MINIMIZED NEED FOR EXPENSIVE "FIXES" AFTER FIRST FLIGHT

DISCIPLINARY PAYOFFS & GOALS

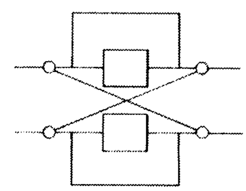
- o VALIDATED AEROSERVOELASTIC ANALYSIS AND DESIGN TOOLS
  - TAILORED WIND TUNNEL MODEL TESTS
- o INCREASED EFFECTIVENESS OF REAL-TIME SIMULATION
  - IMPROVED FIDELITY & REDUCED TIME FOR DESIGN ITERATIONS

This chart shows the prime elements of the LaRC program in Dynamics Integration Research (DIR). It includes methodology development; high-fidelity, batch simulations; validation through real-time piloted simulation; and validation of design methods through aeroservoelastic wind tunnel tests. Each of these activities is integrated and the goal is to develop and validate the tools and methods previously described.

TECHNICAL PLAN

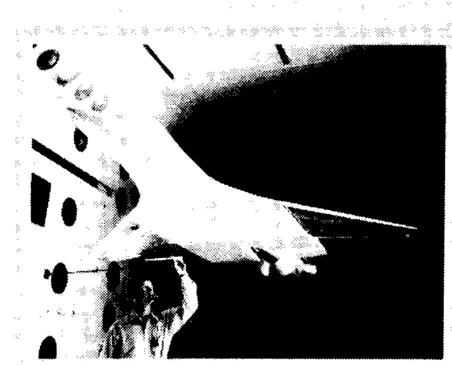


High fidelity model



Integrated control design

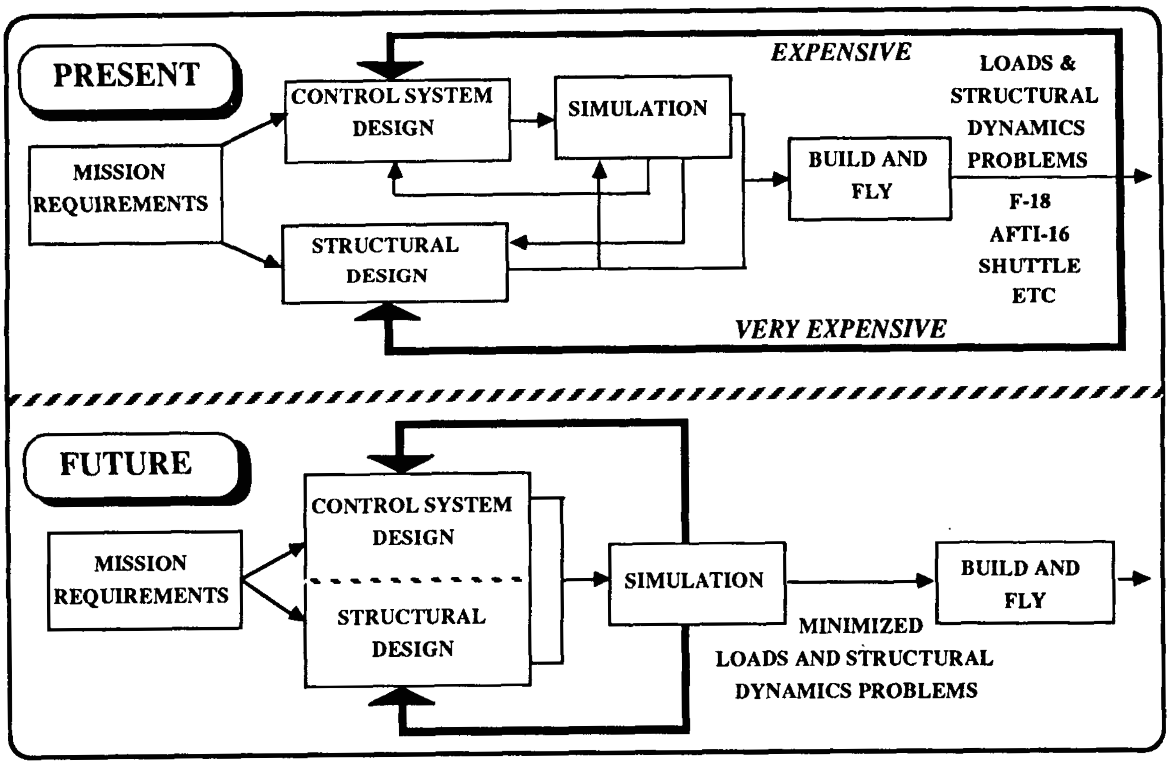
Rapid simulation iteration



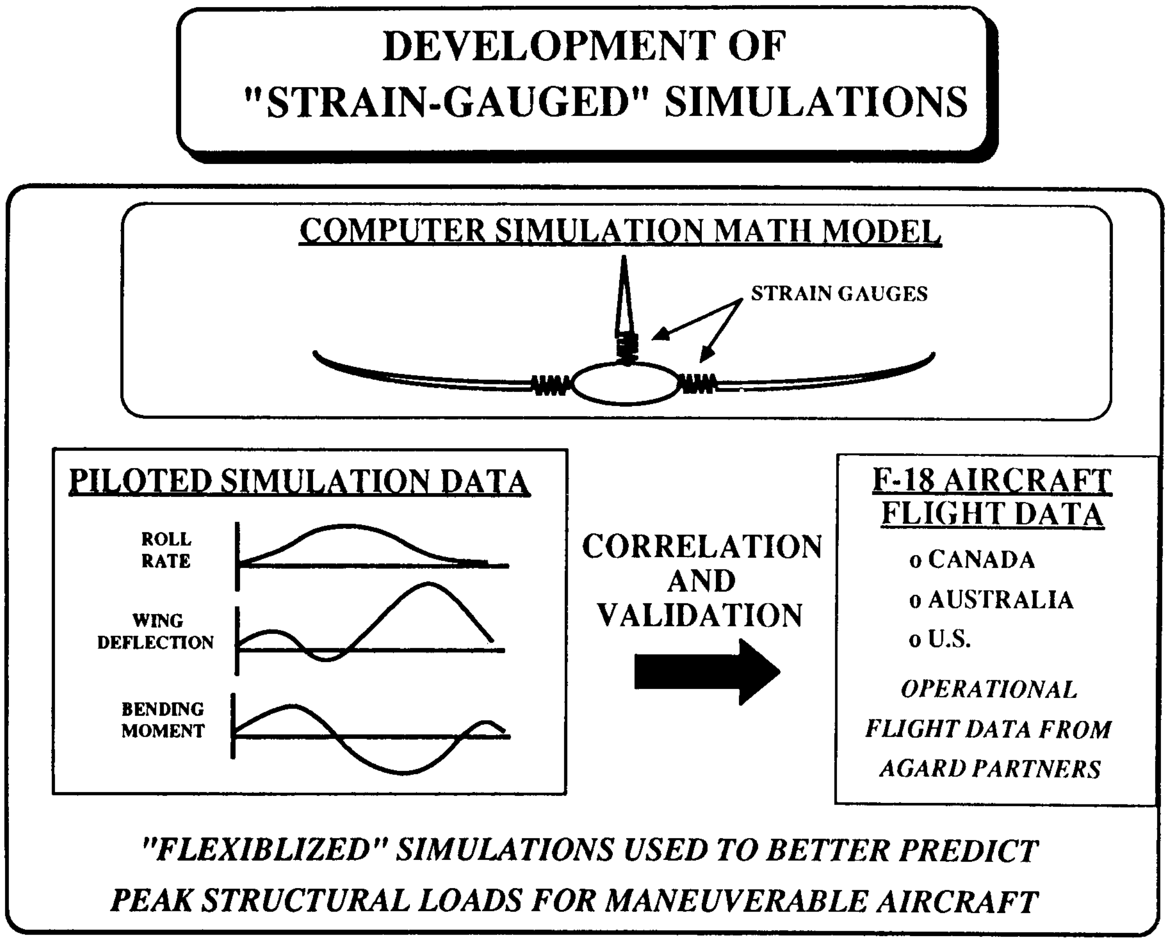
Experimental validation

A comparison of present design methodologies with proposed methodologies that will be enabled through the pursuit of DIR is shown below. Presently, control system design and structural design (for dynamics) are two separate and distinct functions. At some point the control system team typically delivers time histories of typical evaluation maneuvers to the structural dynamicists who analyze for structural load integrity. When the design has converged, the airplane is built and flown. Almost all recent airplanes have had significant problems with structural dynamics, controls systems, and flying qualities. Some examples were described in a previous chart. Once the airplane prototype is built and flown, many options to redesign and fix the problems no longer exist. The two basic options included redesigning the control system, which is quite expensive, and an alternative and less favorable approach, redesigning the structure (and the tooling jig, etc.). This latter option is prohibitively expensive and time-consuming. A better approach would be to allow the two teams to integrate their approaches and work with common models. In fact, if they go to simulation and generate structural loads data as well as flying qualities types of information, the cost of building and flying will be significantly reduced.

METHODOLOGIES FOR SOLVING STRUCTURAL LOADS PROBLEMS

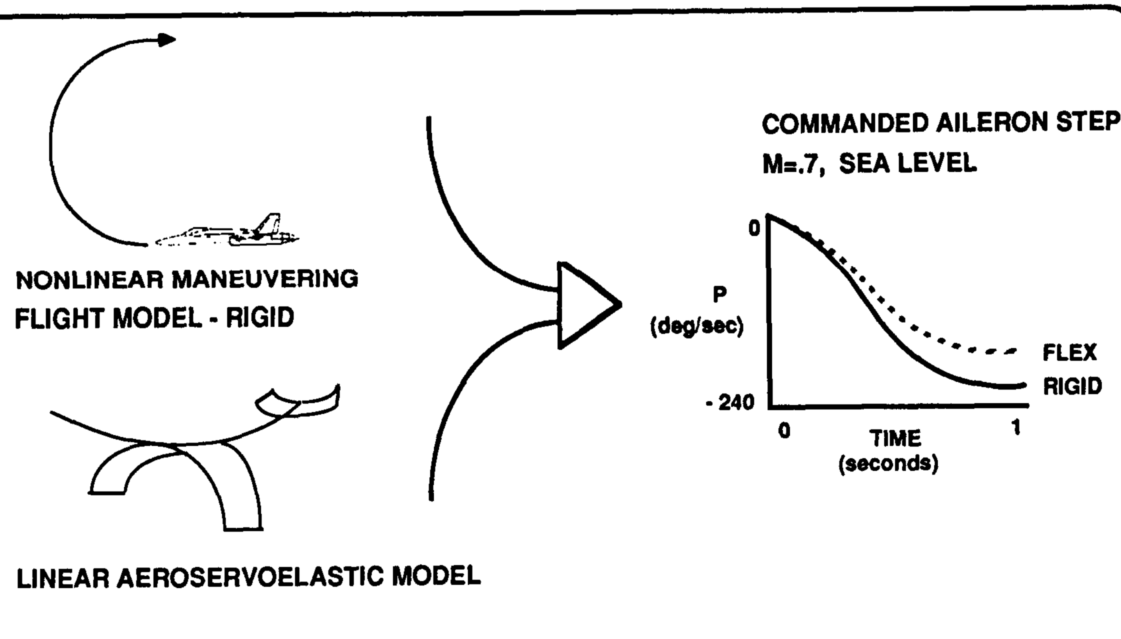


A prime goal will be to build in sufficient modeling fidelity into the real-time simulation model so that in addition to obtaining normal rigid body positions and rates, the deflections and structural loads can be estimated. It is envisioned that these loads will be displayed to test engineers while pilots maneuver their aircraft in realistic scenarios in the simulator. If loads get large or exceed nominal, the test engineer can observe changes in colors at his display and mark the data for indepth analysis. If this scenario becomes possible, test inputs will be obsolete as the pilot will be able to accurately "ring out" the configuration prior to first flight.



One accomplishment that the FIT team has contributed is a modeling methodology that constructs high-fidelity, truth models. The process has been automated significantly and involves integrating information from wind tunnels, CFD and panel, steady aerodynamic codes, unsteady aerodynamic codes and other sources into a nonlinear model. The model maintains the structure needed for nonlinear maneuvers and integrates in the structural dynamics in a rigorous way. During the model integration many terms were uncovered that are typically ignored and could be important for highly maneuverable and flexible vehicles. Tools were developed to check coordinate systems as models were transferred from one discipline to another. The result is a large parent model that is detailed enough to compute air combat maneuvers. When the parent model is trimmed, a by-product is its deflected shape. If the parent model is operated at high enough speed, it flutters. This model is too complex to be used for real-time simulation or probably with direct design tools, but such models could be extracted. The benefit is that if a common model is used for each discipline, the integration process has been fostered.

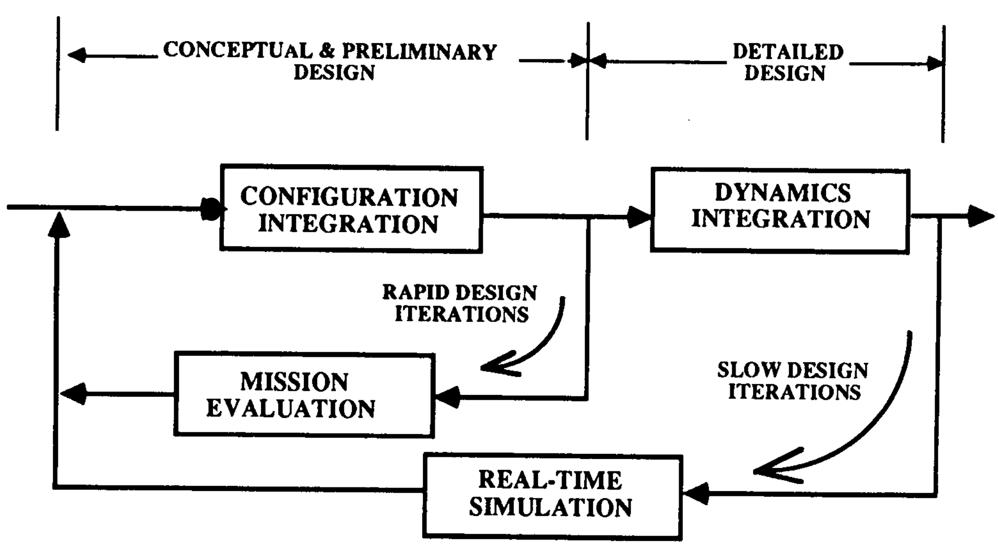
HIGH-FIDELITY, TRUTH MODEL INTEGRATES DISCIPLINES



HIGH-FIDELITY OR TRUTH MODEL HAS BEEN DEVELOPED TO COUPLE AEROSERVOELASTICITY AND FLIGHT DYNAMICS

The design process can be modelled by the flow chart below. The tuning of the vehicle shape tends to occur during the configuration integration loop. The design iterations in this loop can be extremely fast. Dynamics integration normally requires real-time simulation. The effort to build and evaluate real-time simulations is normally a very time-consuming and slow process. The result is that it is difficult for information to flow from the dynamics integration loop in a timely manner to impact the configuration integration process.

CURRENT DESIGN INTEGRATION PROCESS

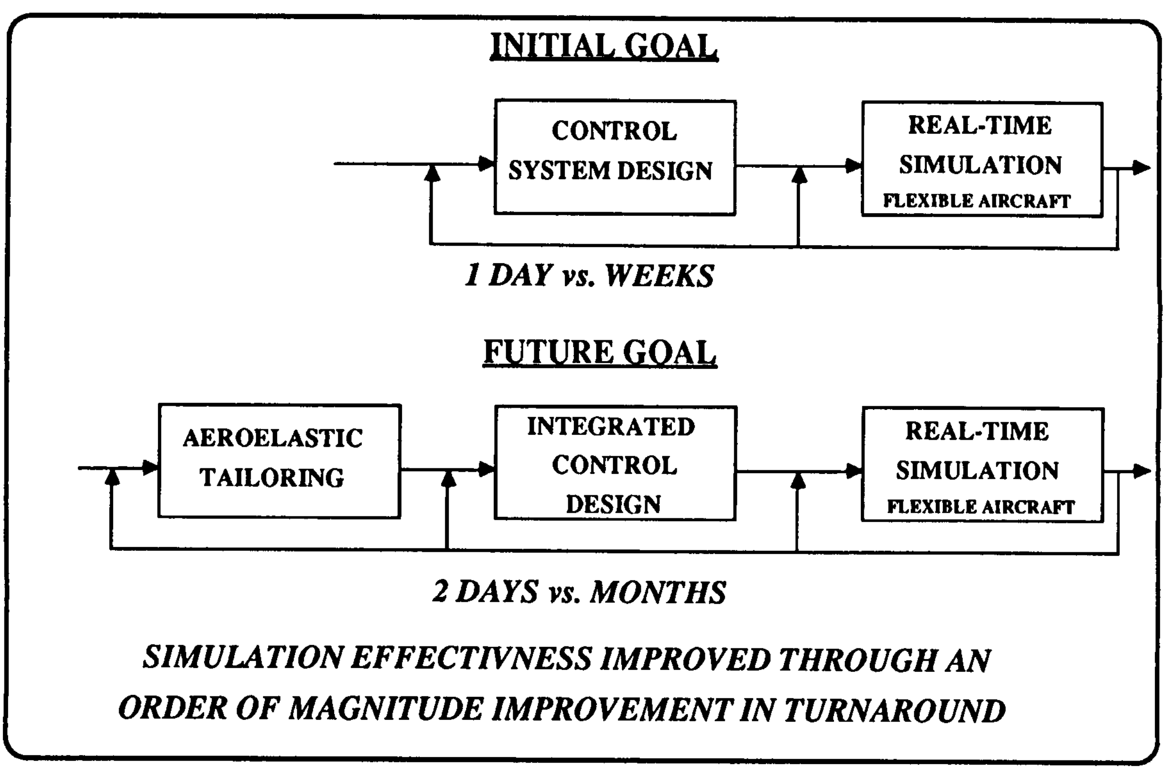


PROBLEM:

DYNAMICS INTEGRATED LATE IN DESIGN PARTIALLY DUE TO SLOWNESS OF UPDATING PILOTED, REAL-TIME SIMULATIONS

The FIT team has established a goal of trying to improve the effectiveness of real-time simulation. One aspect of improving the fidelity by including structural dynamics and aeroservoelastic effects has been discussed previously. Here the goal is to improve productivity and throughput by speeding the process of building and modifying real-time simulations. In particular, the goal is to be able to go from an updated control design to simulation within 1 day. Currently it takes on the order of a week or more to implement a new control system structure for a real-time piloted simulation. Once that goal has been achieved, then the goal will be to combine integrated control design with aeroservoelastic tailoring (in parallel, series or simultaneously). The time-frame desired will be a couple of days versus the months that it takes currently to complete a design and update the appropriate evaluation models.

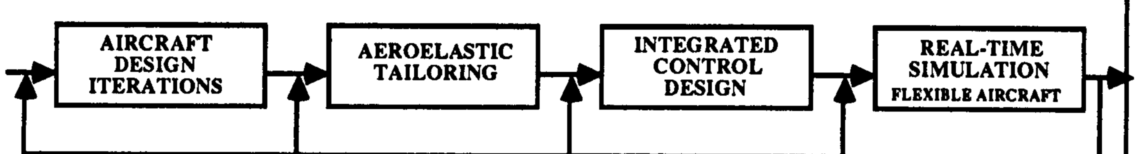
SIMULATION GOALS FOR SPEEDING DESIGN ITERATIONS



Eventually the FIT and ACIG activities will merge and the ultimate goal is that the impact of configuration modifications can be evaluated. Ideally, a configuration variable could be iterated and new models generated and results from a piloted simulation flow back to the designers on the order of a week rather than in several months. If this aggressive goal can be achieved, then dynamic issues can be used to solve configuration problems and improve performance. Additionally, configuration optimization can take place with full knowledge of the impacts it may have on the dynamics of integrated systems.

FUTURE LONG-RANGE GOAL

NEW DESIGN PROCESS

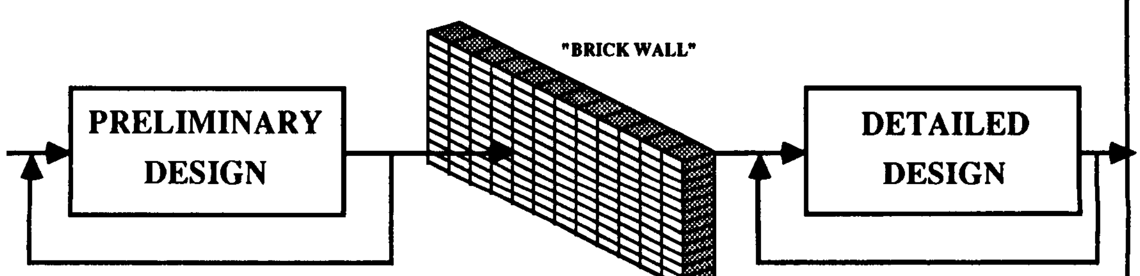


1 WEEK vs. MULTIPLE MONTHS

o ENABLE DYNAMICS ISSUES TO IMPACT CONFIGURATION THROUGHOUT DESIGN PROCESS

Of course, many of the design interactions being discussed occur at the preliminary design level for configuration optimization. In contrast, most of the dynamic system design requires detailed design information. The key obstacle or "brick wall" that prevents such interactions is that it is very time-consuming to develop detailed models. These models either require complicated analyses or experiments, both of which take time to set up and evaluate.

PRACTICAL CONSIDERATIONS TO RAPID DESIGN ITERATIONS



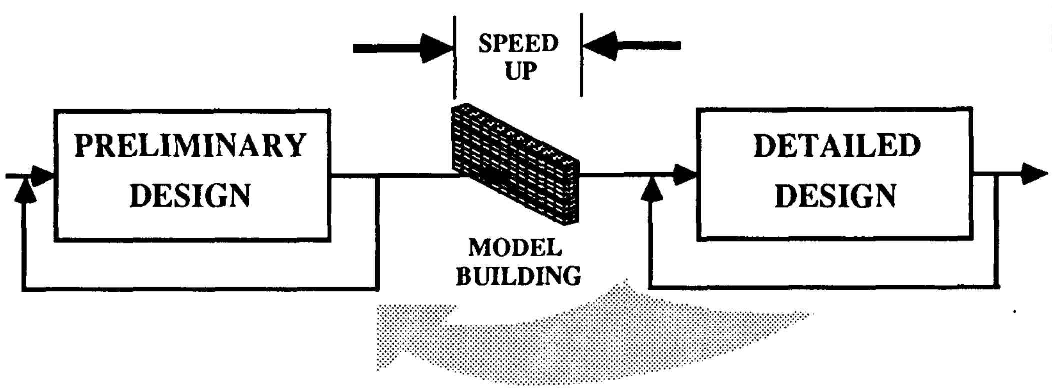
MODEL BUILDING

- **o ANALYSES**
- **o EXPERIMENTS**

DETAILED DESIGN STAGE DELAYED TO GENERATE HIGH-FIDELITY MODELS

The DIR program at LaRC recognizes the shortcomings discussed on the previous page and has developed a strategy for addressing the building of high-fidelity models. Some of the strategies include the following: develop analytical methods for computing interdisciplinary sensitivities which permit decoupled, simultaneous optimization; develop efficient model reduction techniques; pursue generalized trade studies whenever a design problem is undertaken so that the experience can be cataloged and perhaps exploited without going through the entire process for future problem, and; automate the tools in such a way as to speed the model building process.

STRATEGIES FOR IMPACTING PRELIMINARY DESIGN



- o DEVELOP INTERDISCIPLINARY SENSITIVITIES
- o SOLVE MODEL REDUCTION ISSUES
- o GENERALIZE DESIGN TRADES
- o CAPTURE ACCELERATED DETAILED DESIGN METHODS IN PRELIMINARY DESIGN STAGE
- o DEVELOP TOOLS TO SPEED MODEL BUILDING PROCESS

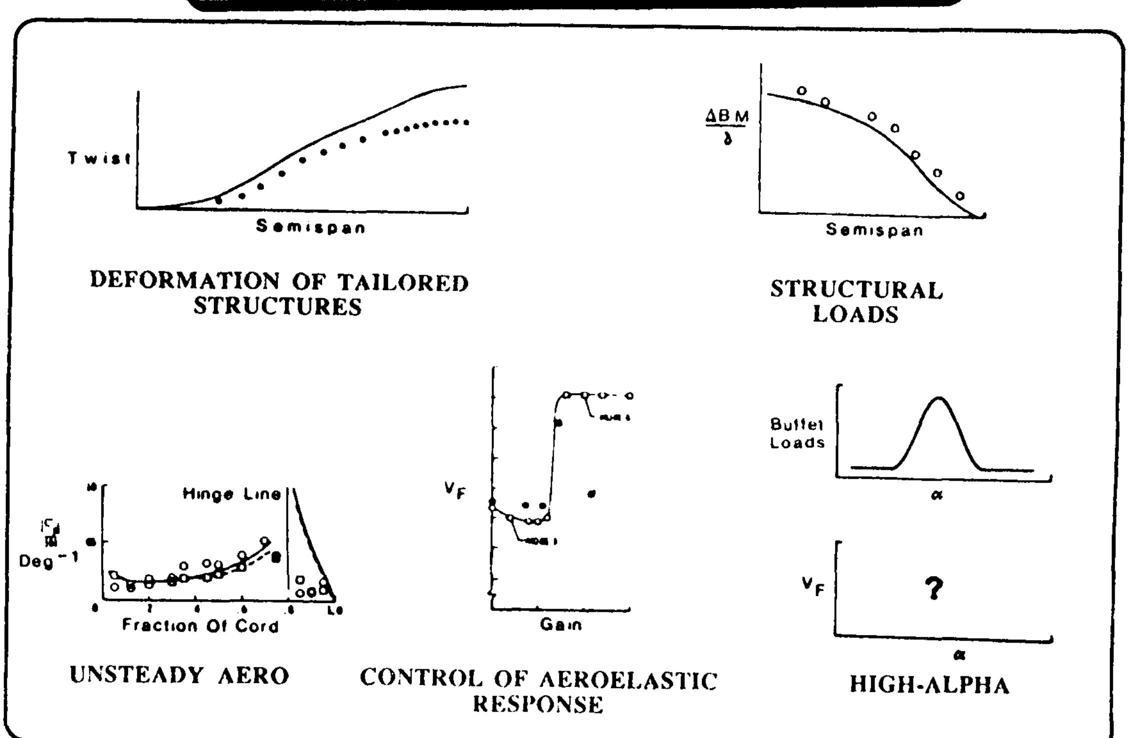
A summary of the key technology areas is shown. For each area a set of challenges is listed. For each challenge, an indication of the status of the available tools in terms of validation and maturity is indicated. As can be seen, at best in this multidisiciplinary focus the validation and maturity status of any particular technology area is marginal. A lot of experimental work is needed to enable designers to address these types of complicated and challenging problems. Methods cannot be integrated into design methodologies unless they have been validated to a sufficient level to permit the confident use of them for vehicle analysis and synthesis.

TECHNICAL AREAS NEEDING EXPERIMENTAL VALIDATION

AREA	CHALLENGES	STATUS
UNSTEADY AERODYNAMICS	o SEPARATED AND VORTEX FLOWS o TRANSONIC o CONTROL EFFECTIVENESS	POOR EMERGING MARGINAL
STRUCTURAL LOADS & RESPONSE	o NON-LINEAR o BUFFET	POOR MARGINAL
AEROSERVO-ELASTICITY	o HIGH GAIN CONTROLS o HIGHLY FLEXIBLE STRUCTURES	EMERGING EMERGING
CONTROL LAW DESIGN	o MULTI-CONTROL o MULTI-FUNCTION	EMERGING EMERGING
STRUCTURE/CONTROL DESIGN	o INTEGRATED STATIC/DYNAMIC AEROELASTIC TAILORING o SENSITIVITY	POOR MARGINAL

This chart shows what it means to validate methods. Various analytical schemes exist already or are under development. These sketches illustrate obtaining experimental data that corresponds directly with analytical data that has been previously computed. This comparison can then be used to investigate improvements in the analytical prediction methods (or perhaps experimental methods).

VALIDATION OF AEROSERVO-ELASTIC ANALYSIS METHODS



This chart outlines the wind tunnel efforts that are planned for the full Dynamics Integration Research (DIR) program, if funded. Key areas needing validation include static and dynamic aeroservoelasticity evaluated transonically and at moderate and high angles of attack. Advanced control law synthesis will be systematically combined with advanced aeroelastic structural synthesis. The prime facility will be the Transonic Dynamics Tunnel. A new capability to evaluate unstable models is currently under way. Ideally, a rigid model should be built for studying unsteady aerodynamics and buffet problems. This could be compared with full-span and semi-span models. Initial tests will be to redesign certain structural or control law parameters of already existing models. If DIR is fully funded, the ultimate goal will be to test and compare these with a fully integrated design.

AEROSERVOELASTIC WIND TUNNEL TEST PROGRAM

o VALIDATION OF ADVANCED ANALYSIS METHODS

- STATIC AND DYNAMIC AEROSERVOELASTICITY
- TRANSONIC UNSTEADY AERO
- HIGH-ALPHA

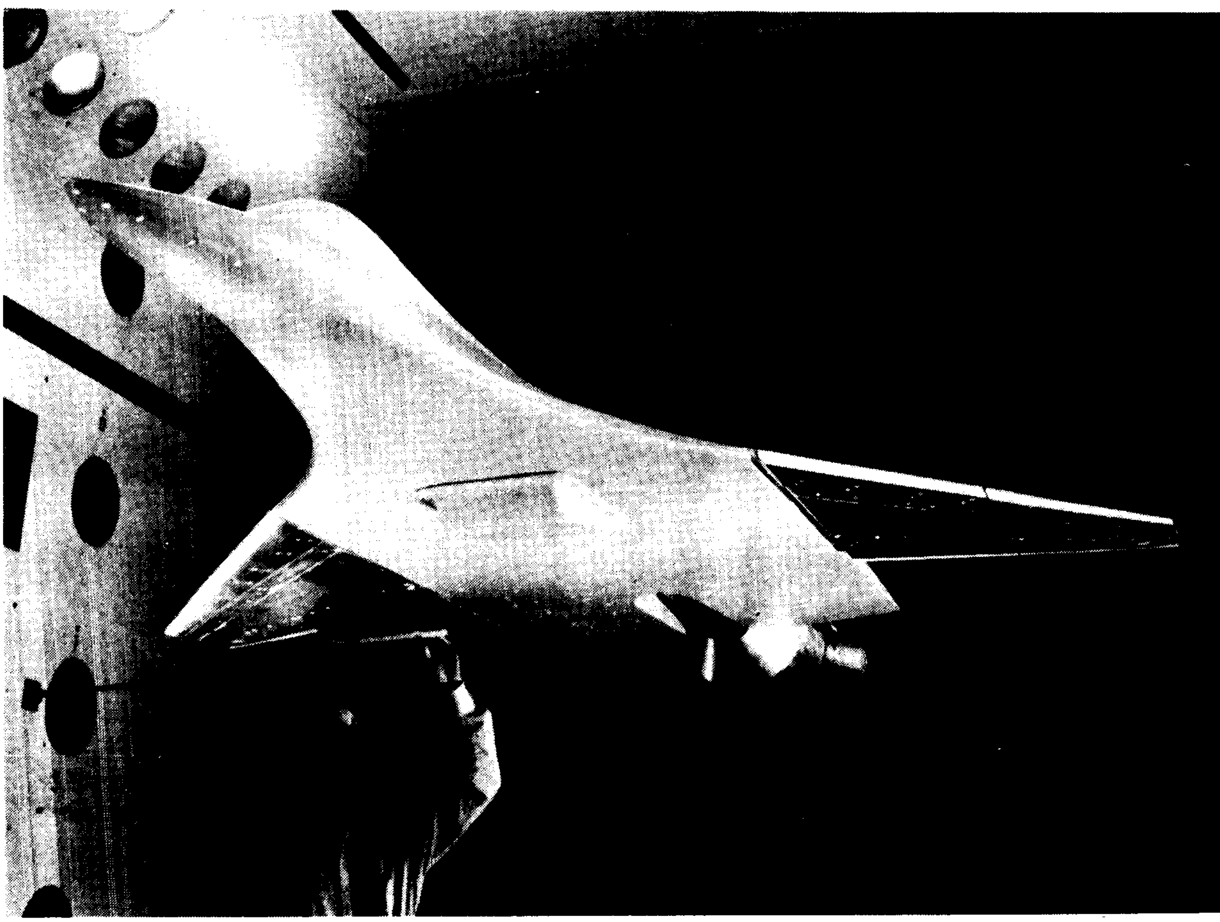
o EVALUATE MULTIDISCIPLINARY DESIGN METHODS

- ADVANCED AEROELASTIC STRUCTURAL SYNTHESIS
- ADVANCED CONTROL LAW SYNTHESIS

o TRANSONIC DYNAMICS TUNNEL (TDT) MODELS

- UNSTABLE MODEL
- RIGID UNSTEADY AERO/BUFFET MODEL
- ACTIVE FLEXIBLE WING
- AEROELASTIC FULL-SPAN

The ongoing Active Flexible Wing (AFW) project is supported by three directorates at Langley Research Center and is a major focus of the FIT team. An advanced model with a highly aeroelastic wing and multiple leading edge and trailing edge control surfaces is a focal point for an aggressive research and testing program. The model has the capability to be free to roll. This allows the simultaneous optimization of flexible and structural modes. Multiple algorithms for combining roll control, load alleviation, and flutter suppression will be evaluated on this model.

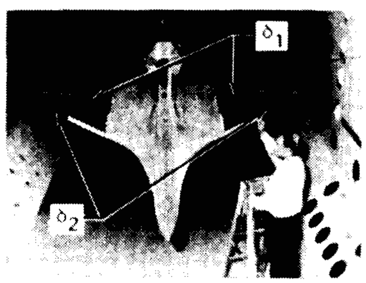


The Active Flexible Wing concept model has already been utilized in research experiments through two previous wind tunnel entries. The control law parameterization plot indicates that constant performance and stability may be obtained for a range of control surface deflections. Control surface deflection is a measure of the effort required by the control system to perform its function. This plot, and others like it, allow the engineer to minimize that effort by proper choice of gain factors. In a similar manner wing loads during roll maneuvers may be minimized by an alternate choice of gain factors. Additionally, relatively good agreement between analysis and experiment is indicated.

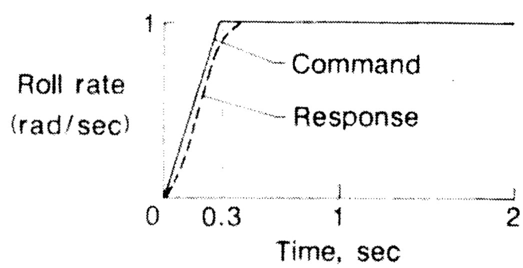
AEROSERVOELASTIC ANALYSIS VALIDATED BY WIND TUNNEL TESTS

Mach = 0.90 Dynamic pressure = 250 psf

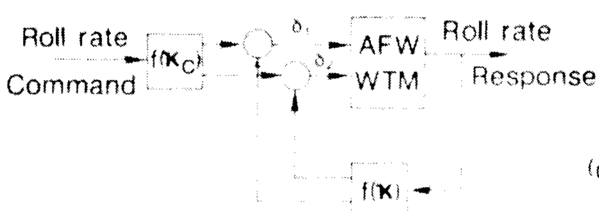
Active flexible wing model



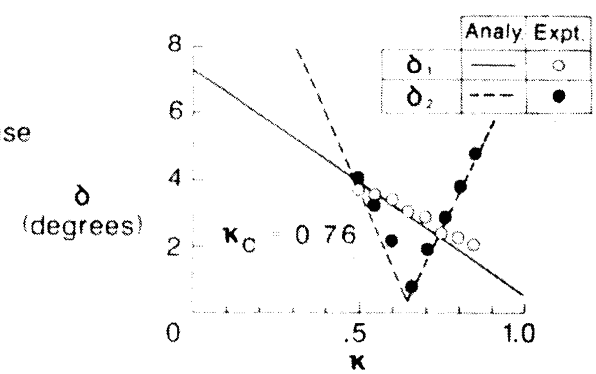
Roll rate performance



Block diagram of active roll control system

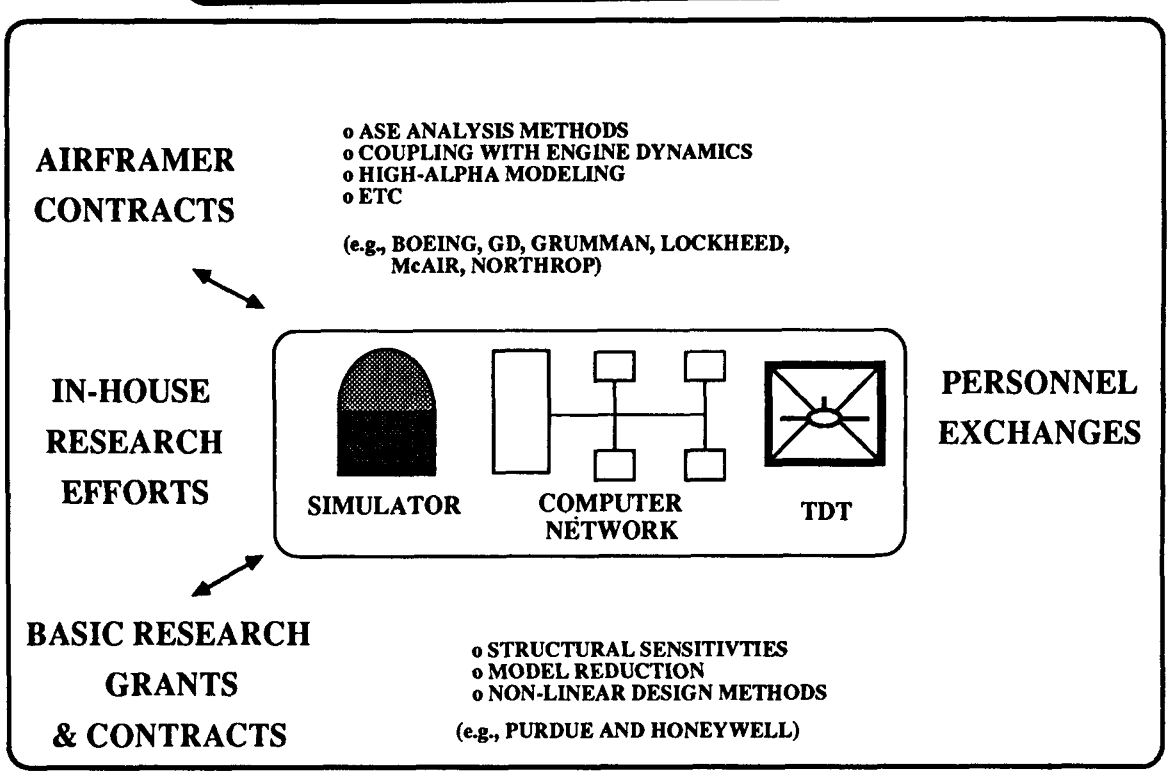


Control law parameterization



The DIR program, if funded, is envisioned as a multidisiciplinary research activity that will exploit in-house NASA research, academic research, contracted research, and system integration by the major airframers to document the benefits of synergistically combining the critical technologies. Many organizations have expressed interest in this research topic and many believe that it is important to document the benefits of early inclusion of this technology in aircraft of all classes.

COLLABORATIVE RESEARCH OPPORTUNITIES



This chart summarizes this presentation. Langley has pursued an aggressive in-house program of multidisiciplinary research combining elements of structural dynamics, aeroservoelasticity, and flight controls. Good technical progress has been made in analysis and modeling methodologies. Application to the synthesis problem is being pursued as an important part of the Active Flexible Wing project. In the event of full funding, partnerships between NASA and other parts of the aerospace community are expected.

CONCLUDING REMARKS

- LaRC HAS EMBARKED ON AN AGGRESSIVE IN-HOUSE PROGRAM TO INTEGRATE STRUCTURAL DYNAMICS, AEROSERVO- ELASTICITY, FLIGHT MECHANICS AND FLYING QUALITIES
- THERE EXISTS A TREMENDOUS OPPORTUNITY FOR SIGNIFICANT PERFORMANCE GAINS
- THE FIT TEAM HAS BEEN WORKING TOGETHER FOR 3 YEARS PLUS; HAS DEVELOPED NEW MODELING METHODOLOGIES THAT RIGOROUSLY COMBINES THE DISCIPLINES
- THE ACTIVE FLEXIBLE WING PROJECT IS A MULTIDISCI- PLINARY ACTIVITY IN WHICH MEMBERS OF THE FIT TEAM ARE PARTICIPATING
- FUNDING TO ACCELERATE AND PROVIDE TEAMING ARRANGEMENTS IS BEING SOUGHT